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Modeling the near-field ionospheric disturbances during earthquakes

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Outline

- Introduction to seismic-ionosphere coupling
- Developing seismic-ionosphere coupling model WP-GITM
- Simulation of the 16 September 2015 Illapel earthquake
- Summary

Introduction to seismic-ionosphere coupling I

- Ground shaking during earthquakes can excite upward-propagating acoustic-gravity waves in the atmosphere.
- As the acoustic-gravity waves propagating upward, their amplitudes grow with altitude to conserve energy due to the decreasing background air density.
- When the acoustic-gravity waves reach the ionosphere, they perturb the charged particles through neutral-ion coupling.
- Ionospheric disturbances following earthquakes have been observed widely [e.g.,Davies & Baker, 1965; Calais & Minster, 1995, …].

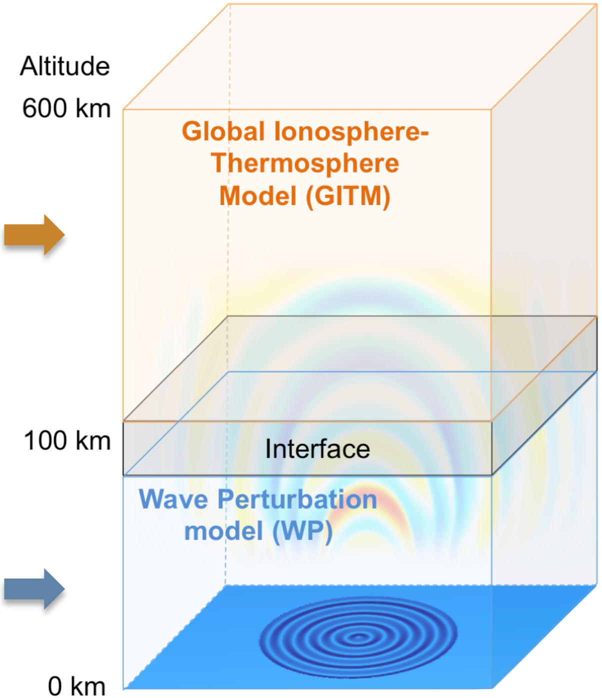
Introduction to seismic-ionosphere coupling II

- The seismic-ionosphere coupling process is still not well understood.
- As more observational data are being collected and analyzed, numerical models [e.g., Heki & Ping, 2005; Rolland et al., 2011, 2013; Zettergren et al., 2015, 2017] have been developed to investigate the physics behind the seismic-ionospheric coupling.
- Most models either reply on empirical models of the neutral atmosphere and ionosphere or does not solve the ionospheric electrodynamics self-consistently.
- To overcome these limitations, we have developed a new seismic-ionosphere coupling model [Meng et al., 2018], Wave Perturbation-Global Ionosphere-Thermosphere Model (WP-GITM). **WP-GITM** is built upon an existing and well-validated state-of-the-art model of the upper atmosphere, GITM [Ridley et al., 2006], that is 3-D, fully physics-based, non-hydrostatic, and inclusive of self-consistent ionospheric electrodynamics.

Model development I

WP-GITM infrastructure

Input I
solar wind conditions, solar irradiance, auroral particle precipitation



Input II
surface (ground/ocean) vertical velocity from seismic measurements

Output
Ionospheric and thermospheric disturbances

Model development II

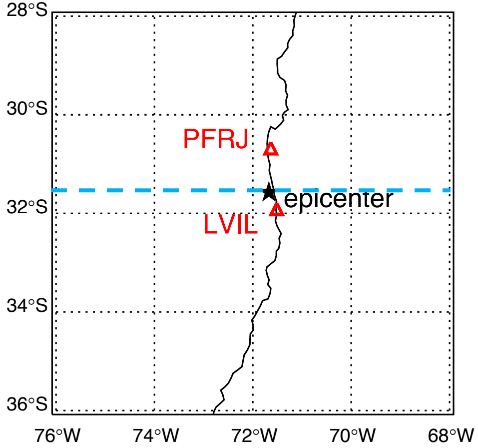
- **Focus:** near-field (within 1000km from epicenter) seismic-ionosphere coupling.
- The near-field ionospheric disturbances are mainly contributed from two types of ground motions: 1) the epicentral crustal movement in the vertical direction; and 2) the Rayleigh surface waves and seismic vertical shear waves propagating outward from the epicenter.
- Our previous modeling work [Meng et al., 2018] addressed the first type. A point source was assumed, therefore the radiation pattern of the seismic source was neglected.
- For this work we address the second type and include the asymmetric radiation pattern of seismic sources.

Model development III

- To include the Rayleigh-surface-wave-induced atmospheric and ionospheric perturbations, we assume that the Rayleigh-surface waves expand circularly outward from the epicenter and the resulting atmospheric acoustic-gravity waves follow the same expansion pattern.

- To include the radiation pattern of a seismic source, we utilize seismic measurements from more than one location at different directions from the epicenter to drive WP-GITM. For the 16 September 2015 Illapel earthquake, seismic measurements from two locations were taken, one to the north of the epicenter, the other to the south of the epicenter.

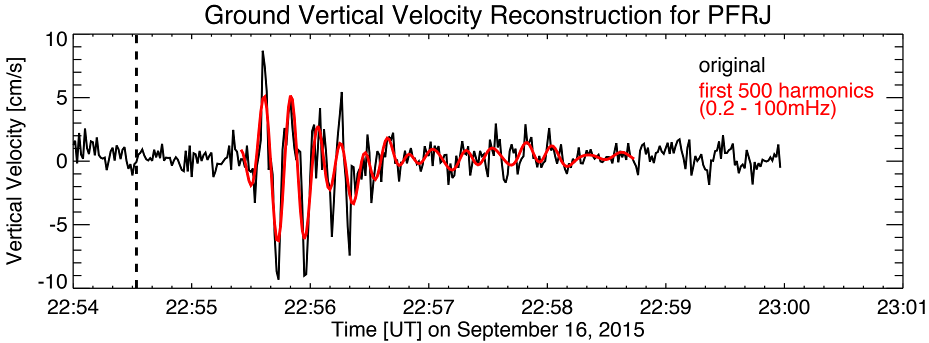
Simulation of the 2015 Illapel earthquake: source specification

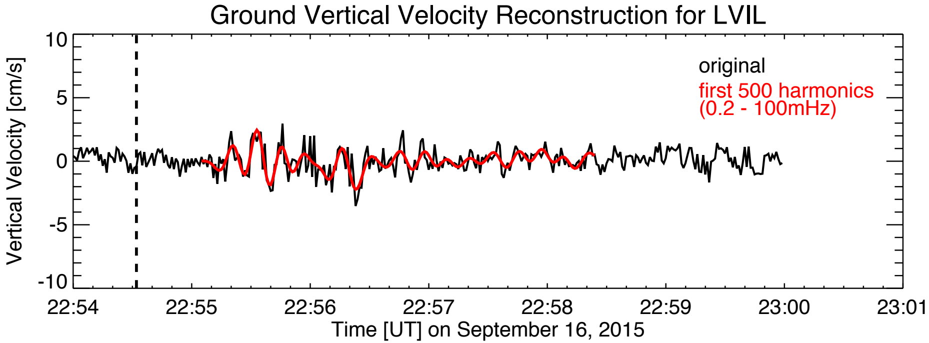


The ground motion north of the epicenter is specified based on the data from PFRJ; south based on LVIL.

The vertical velocities decay with epicentral distance r at a rate of $\sqrt{r}$

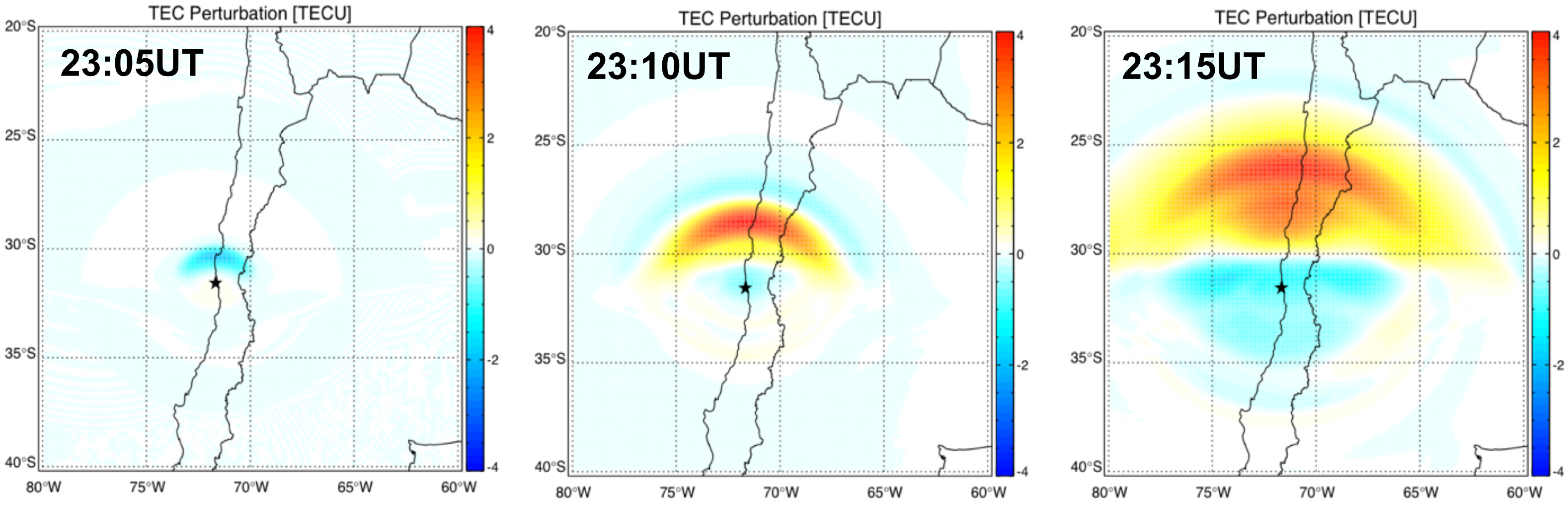
Input to WP-GITM





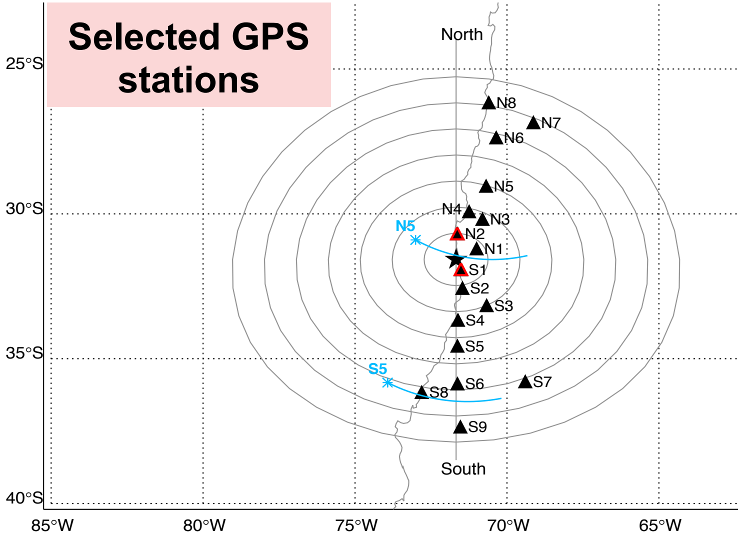
Simulation of the 2015 Illapel earthquake: Total electron content (TEC) perturbations

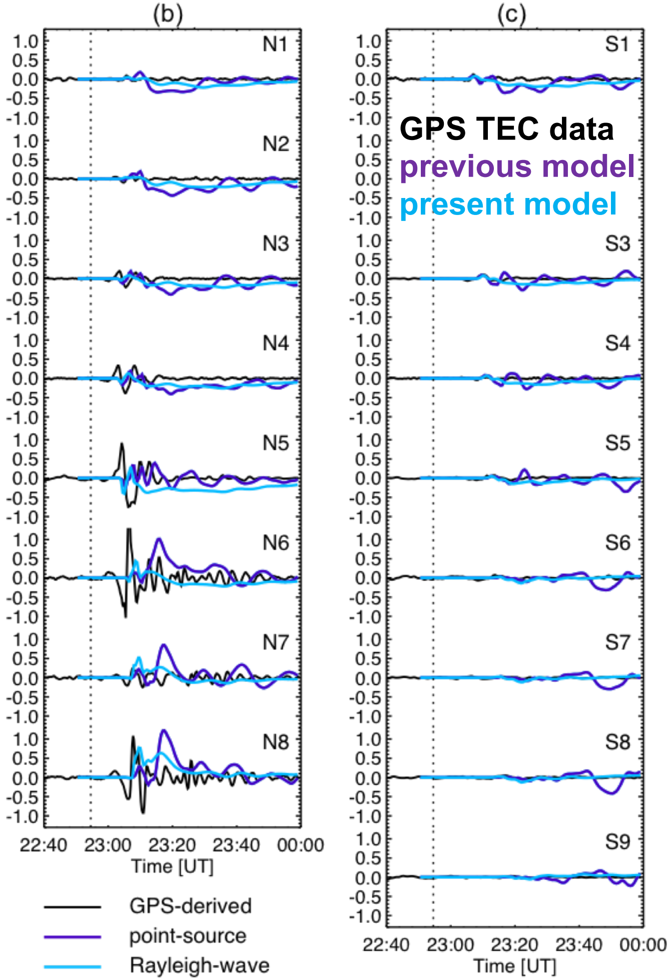
WP-GITM simulated ionospheric TEC perturbations [TECU]



The simulated TEC perturbations show a strong north-south asymmetry, which is expected and comes from the ground motion data used to drive the model. The difference in TEC perturbation magnitudes is coherent with the difference in the ground motion strengths at PFRJ and LVIL.

Simulation of the 2015 Illapel earthquake: comparison with GPS TEC data





The present model better matches the arrival times of the most profound peak in TEC perturbations than the previous point-source model for north stations.

Summary

- We have augmented new features to the existing earthquake-ionosphere coupling model WP-GITM in order to capture the Rayleigh-wave-induced ionospheric disturbances and include the effects of asymmetric radiative pattern of the seismic source.

- The new model development incorporates

  1) circularly-expanding and vertically-propagating acoustic-gravity waves to represent the Rayleigh-surface-wave-induced atmospheric perturbations in the near-field region, and

  2) the ground motion data from seismic measurements at two locations as inputs.

Summary

- Modeling results from the 2015 Illapel earthquake are promising.
  - The simulation reproduces the north-south asymmetry in the TEC perturbation magnitudes found in the observations.
  - The simulation matches the arrival times of TEC perturbations better than the point-source-driven simulation for stations some distance away from the epicenter, where the Rayleigh surface waves play a more dominant role in causing the vertical ground motion.

- Next, we will extend WP-GITM to accommodate seismic measurements from many more locations to better resolve the azimuthal variation and the radiation pattern of the seismic source, which would more accurately represent the ground motion in the near-field region.

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